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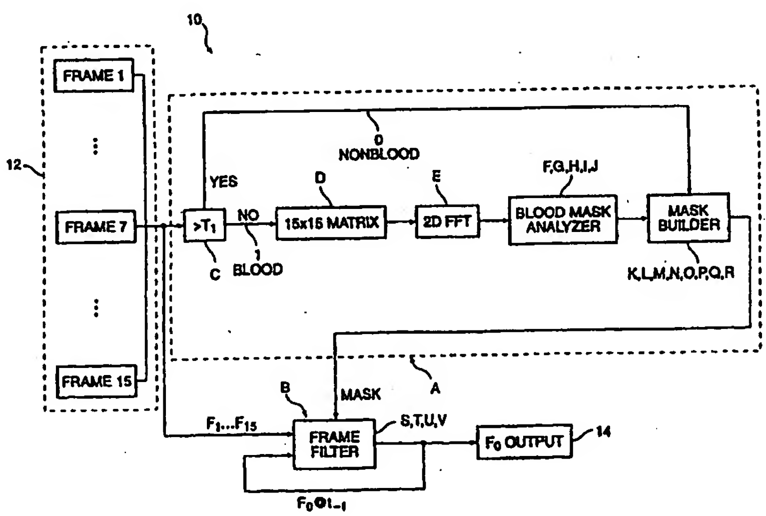
(54) Title: METHOD AND APPARATUS FOR SPATIAL AND TEMPORAL FILTERING OF INTRAVASCULAR ULTRASONIC IMAGE DATA



(57) Abstract

A method and an apparatus (10) are provided for combining spatial and temporal filtering for blood speckle reduction in high frequency ultrasound images wherein a sequence of image frames (input 12) is processed to produce a binary mask. In this mask, a first value is assigned to regions of identified blood speckles and a second value is assigned to regions of the remainder. The images are then modulated with the mask to produce output frame (14), i.e., by applying different filtering techniques to assigned blood regions and assigned nonblood (i.e., tissue) regions, the filtering techniques having been selected to optimize images for the type of feature to be highlighted based on differences in frequency sensitivity between blood and tissue. The images are preferably in polar coordinate format. The degree of blood speckle suppression can be determined based on the actual values of the pixels at the same spatial location in given frames.

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METHOD AND APPARATUS FOR SPATIAL AND TEMPORAL FILTERING OF INTRAVASCULAR ULTRASONIC IMAGE DATA

BACKGROUND OF THE INVENTION

This invention relates to intravascular ultrasonic imaging, particularly to data processing techniques for improving image perception.

With the increasing frequency (above 40MHz) ultrasonic signals, blood speckles appear more prominently in ultrasonic intravascular images. The speckles are sufficiently bright to lower the contrast between blood and tissue, making it harder for physicians to determine the true boundaries based on a single frame images.

Most blood speckle reduction algorithms use either spatial or temporal information only, which is insufficient to determine the characteristic. See, for example, B. Olstad, "Noise reduction in ultrasound images using multiple linear regression in a temporal context", SPIE, vol. 1451, pp.269-281, 1991; Olstad, et al., "Analysis and measurement of temporal tissue variations", US Patent 5476096, 1995; and Karaman, et al., "An adaptive speckle suppression filter for medical ultrasonic imaging", IEEE Trans. Med. Imag., vol.14, pp.283-292, 1995.

Some algorithms have attempted to combine spatial and temporal filtering. However, they are so complex and cumbersome that processing cannot be realized in real-time with known technology. See, for example, Evans, et al., "Biased Motion-Adaptive Temporal Filtering for Speckle Reduction in Echocardiography", IEEE Trans. Med. Imag., vol.15, pp.39-50, 1996.

Tissue tends to be static over short periods of time. Blood cells move rapidly so blood speckles are randomly scattered. However, due to the fast cardiac motion and speckling nature of the high frequency ultrasound signals, it is difficult to differential blood and tissue without the

consideration of additional information, such as spatial properties. What is needed is a near real-time technique for suppression of spurious dynamic artifacts.

SUMMARY OF THE INVENTION

According to the invention, a method and an apparatus are provided for combining spatial and temporal filtering for blood speckle reduction in high frequency ultrasound images wherein a sequence of image frames is processed to produce a binary mask, preferably a two-dimensional binary mask. In this mask, a first value is assigned to regions of identified blood speckles and a second value is assigned to regions of the remainder. The images are then modulated with the mask, applying different filtering techniques to assigned blood regions and assigned nonblood (i.e., tissue) regions, the filtering techniques having been selected to optimize images for the type of feature to be highlighted. The preferred filtering technique is a spectral analysis of transformed data so that the energy content of features changing at higher frequencies can be weighed against features changing at lower frequencies. The images are preferably in polar coordinate format. The degree of blood speckle suppression can be determined based on the actual values of the pixels at the same spatial location in given frames.

In a specific embodiment, the process of generating the mask involves obtaining a vector in each frame for the given frames at the same spatial location to produce a two-dimensional matrix, with the matrix then being transformed to the frequency domain to determine its characteristics. A binary label is derived and given to the pixel that is located at the center of the vector in the current frame, indicating whether it is blood speckle. Assuming the blood clutter and tissue are not isolated, a morphologic operator is applied to the first mask and then isolated labels are removed.

Once the mask is generated, different operations are performed on the original input frames. This is done on a pixel-by-pixel basis. For a pixel which is labeled as tissue,

an average with the previous output value is used. For a pixel which is labeled as blood speckle, a minimum value is derived from values of this pixel in the given image frames.

The invention will be better understood by reference to the following detailed description in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an apparatus according to the invention.

Fig. 2A is a flow chart of a first part of the process according to the invention.

Fig. 2B is a flow chart of a second part of the process according to the invention.

Fig. 3 is a spectral diagram of a fast Fourier transform of image data.

DESCRIPTION OF SPECIFIC EMBODIMENTS

In order to efficiently combine spatial and temporal filtering, patterns should be identified in regions of interest generated by both the dimensions of time and of space. For example, a vector is obtained along the θ dimension from each image frame within a certain time window, the so called θ-Time filtering window. It has been discovered that, in the θ dimension, neighboring pixels have similar intensities in tissue, while they may appear to be more scattered in the blood area. Tissue regions and blood regions have been observed to exhibit spectral sensitivity in the both time dimension and the angle (θ) dimension, albeit differently. Blood exhibits greater reactivity with higher frequency. These characteristics are useful for distinguishing blood and tissue in imaging.

In the present invention, a specified number of consecutive frames is made available for digital analysis. Fig. 1 is a block diagram of an apparatus 10 according to the invention that illustrates an implementation. In this example, input is a sliding window 12 comprising fifteen image

frames (F1,..., F15) which are processed together to generate one output frame (Fo) 14.

All images are in raw data format whose pixel values represent the value at every r and θ coordinate.

Referring to the flow chart of Fig. 2A in connection with Fig. 1, the process to generate a blood speckle reduction frame includes two major steps:

A. For each frame generate a binary mask indicating blood regions (value 1) and non-blood regions (value 0) by comparison of an analyzed intensity value at each pixel in relation with previous frames and in relation to a adjacent pixels with a selected threshold intensity value.

B. Apply the mask obtained in Step A to a block of raw (original) frame data (F1-F15) and to the previous output frame (Fo @t-1)) to generate the new output frame (Fo).

In operation, an input buffer 12 containing the fifteen consecutive frames and the output frame is provided for storage.

In the first major step, each pixel in r and θ is examined for its characteristic intensity (Step C). For each pixel intensity $I(r,\theta)$ in the current frame (in this example, the center frame, Frame 7), if the pixel intensity is larger than a preset value T1, it is tentatively considered to be non-blood (tissue), and value 0 is assigned to the corresponding pixel. This is an indication that further gray scale analysis will not be required. Otherwise, value 1 is assigned as tentatively being blood, and an image intensity matrix $M(r,\theta)$ of 15x15 is formed (Step D), as hereinafter explained to further refine whether the pixel is of blood or nonblood. Specifically, each column of this matrix consists of a block of fifteen neighboring pixels in an angular (θ) direction in the same time frame. Each row consists of pixels at the same location in successive time frames. Hence, a matrix in space and time is formed.

In the example illustrated in Fig. 1, the interim 15x15 matrix is constructed in the form:

$$M(r, \theta) = [v1\ v2\ \ldots\ v14\ v15]$$

where

$vt = [I(r,\theta-7) \ldots I(r,\theta) \ldots I(r, \theta+7)]^T$, $t = 1, 2, \ldots, 15$

Signal processing operations can then be performed on matrix $M(r,\theta)$ to discriminate between tissue and blood in the region containing tissue. First, a two-dimensional 16x16 FFT of the matrix is computed, with zero padding on the last row and last column of the 15 by 15 matrix to 16 by 16 (Step E). Then, from the spectral results of the FFT, a spectral analysis is performed wherein a ratio is computed between the total power of high frequency components and the total power of low frequency components (excluding the DC component) (Step F). See Fig. 3 for a spectral diagram of the fast Fourier transform. While the transition between low frequency components and high frequency components is not precise, it can be selected for example to be at between the third and the fifth harmonic, the ratio of high frequency components to low frequency components tends to be sufficiently higher in a blood region than in a tissue region so that this ratio can be used as a metric. If the ratio R is greater than a dimensionless threshold Tr (Step G), the position in the matrix M is set to 1 and identified as blood (Step H). If the ratio R is less than the threshold Tr, the position in the matrix M is set to 0 and identified for further processing (Step I). The process is repeated for each pixel location {i,j} (Step J). Because tissue at a distance from the center of a region reacts more like a blood region in the spectral domain, this method is useful for detecting a tissue ring that encloses a blood pool.

Further processing is needed to produce a reliable binary mask separating tissue (nonblood) and blood. First, a technique is used to remove pixels tentatively but falsely identified as blood based on a count of blood-designated pixels in the neighborhood. This technique is based on the knowledge that blood regions are known to be relatively large and cannot be isolated points. Referring to Fig. 2B, for each pixel, the number of neighboring pixels with label as blood is counted (Step K) and if the number is substantially small (Step L), this pixel is labeled as tissue (Step M). Otherwise

it is labeled as blood (Step N). This process is repeated for each pixel {i,j} (Step O).

Second, each radial direction is scanned for maximum intensity of the tissue point (Ym or MITP) in this radial direction (Step P). Based on the assumption that blood pools are surrounded by tissue, all pixels after, or further away than, the MITP are labeled as tissue (set to zero) (Step Q). This is repeated for all coordinates of j, the radial direction (Step R). The mask is thus built (Step A).

The next steps (comprising Step B) yield the so-called filtered frame, wherein each pixel value in the output is derived from the following: for every point $M(r, \theta)$ in M, if its value is 1 (Step S), this point is characterized as blood and needs to be suppressed. For example, the corresponding point in the output is set to the minimum value of $I(r, \theta)$ in all frames or subset of frames (e.g., 5 frames) (Step T). Otherwise, for a tissue point, where the value is 0, an average of the original intensity value and the intensity of the same point in the previous output frame can be used as the output value (Step U). These assignments or calculations are carried out for every pixel location {i,j} (Step V).

This invention has numerous advantages. This approach can enhance the edge between lumen (blood) and vessel wall (tissue), providing more clear border definition in an intravascular ultrasonic imaging system. This spatial and temporal analysis of the interior of a vascular region using signal processing techniques enhances the identifiable image distinction between blood and tissue. This approach is more efficient in that it combines a time dimension with only one spatial dimension, and so it need not involve higher dimensional analysis.

The invention has been explained with reference to specific embodiments. Other embodiments will be evident to those of ordinary skill in the art. It is therefore not intended that this invention be limited, except as indicated by the appended claims.

WHAT IS CLAIMED IS:

1. A method for filtering of ultrasonic image data in a contained zone in order to identify non-blood (tissue) and blood comprising:

generating a binary two-dimensional mask indicating both blood regions and non-blood regions in a center frame in time based on intensity values of adjacent pixels of the center frame and of adjacent pixels of a sequence of said frames, source data for said generating step employing only one spatial dimension with a time dimension; and

filtering the center frame by employing said binary mask to a two-dimensional block of frame data including unprocessed frame data for the center frame and adjacent frames in sequence, and processed frame data of a prior output frame, in order to obtain a new output frame.

2. The method according to claim 1 wherein said binary mask generating step comprises:

identifying tentative non-blood regions for gray scale analysis;

identifying all other regions as tentative blood regions; and

spectrally analyzing intensity of said tentative blood regions over time and space to identify additional non-blood regions for gray scale analysis.

3. The method according to claim 2 wherein said spectral analyzing step comprises:

transforming intensity data over space and time of said tentative blood regions into the frequency domain;

comparing high-frequency components with lower frequency components of each pixel of the center frame in order to denominate pixels with more higher frequency components as blood regions.

4. The method according to claim 3 wherein said filtering step comprises:

suppressing intensity values of blood region pixels; and

averaging over time and space intensity values of non-blood region pixels.

5. The method according to claim 1 wherein said filtering step comprises:

suppressing intensity values of blood region pixels; and

averaging over time and space intensity values of non-blood region pixels.

6. The method according to claim 2 wherein said spectral analysis is performed for all pixels in said tentative blood regions within non-blood regions.

7. The method according to claim 5 wherein said filtering step further comprises:

identifying points of maximum intensity along radials of non-blood regions; and

designating points along said radials beyond said points of maximum intensity as non-blood regions.

8. A method for filtering of ultrasonic image data in a contained zone in order to identify non-blood (tissue) and blood comprising:

generating a binary mask indicating both blood regions and non-blood regions in a center frame in time based on intensity values of adjacent pixels of the center frame and of adjacent pixels of a sequence of said frames; by

identifying tentative non-blood regions for gray scale analysis;

identifying all other regions as tentative blood regions; and

spectrally analyzing intensity of said tentative blood regions over time and space to identify additional non-blood regions for gray scale analysis; by

transforming intensity data over space and time of said tentative blood regions into the frequency domain; and

comparing high-frequency components with lower frequency components of each pixel of the center frame in order to denominate pixels with more higher frequency components as blood regions; and

filtering the center frame by employing said binary mask to a two-dimensional block of frame data including unprocessed frame data for the center frame and adjacent frames in sequence, and processed frame data of a prior output frame, in order to obtain a new output frame.

9. An apparatus for spatial and temporal filtering of ultrasonic image data of a contained zone in order to identify non-blood (tissue) and blood comprising:

a binary two-dimensional mask generator for indicating both blood regions and non-blood regions in a center image frame in time, said generator observing intensity values of adjacent pixels of the center frame and adjacent pixels of adjacent frames in sequence, source data for said generator being constrained to be of only one spatial dimension and a time dimension; and

a blood/non-blood filter employing said binary mask on a block of frame data including unprocessed frame data for the center frame and adjacent frames in sequence, and processed frame data for a prior output frame, in order to obtain a center output frame identifying blood regions and non-blood regions.

10. The apparatus according to claim 9 wherein said binary mask generator comprises:

a signal transformer for converting a block of time domain components and spatial components into the frequency domain in order to permit analysis of temporal and spatial characteristics of a center frame;

means for computing a ratio of higher frequency components to lower frequency components; and

comparator means for comparing said ratio to a threshold ratio in order to distinguish between blood regions and non-blood regions on a spectral basis in the frequency domain.

11. The apparatus according to claim 10 further including:

means responsive to location and intensity of pixels for locating a point of maximum intensity along each radial of the non-blood regions; and

means for designating lengths along each said radial beyond each said point of maximum intensity as non-blood regions.

12. The method according to claim 9 wherein said blood/non-blood filter comprises:

means for suppressing intensity values of the blood region pixels;

means for averaging, over time and space, intensity values of non-blood region pixels; and

means for generating from said averaged intensity values of said non-blood region pixels values and from said blood region pixels having suppressed intensity values, an output frame identifying blood regions and exhibiting said averaged intensity values of said non-blood regions.

13. An apparatus for spatial and temporal filtering of ultrasonic image data of a contained zone in order to identify non-blood (tissue) and blood comprising:

a binary mask generator for indicating both blood regions and non-blood regions in a center image frame in time, said generator observing intensity values of adjacent pixels of the center frame and adjacent pixels of adjacent frames in sequence; and

a blood/non-blood filter employing said binary mask on a block of frame data including unprocessed frame data

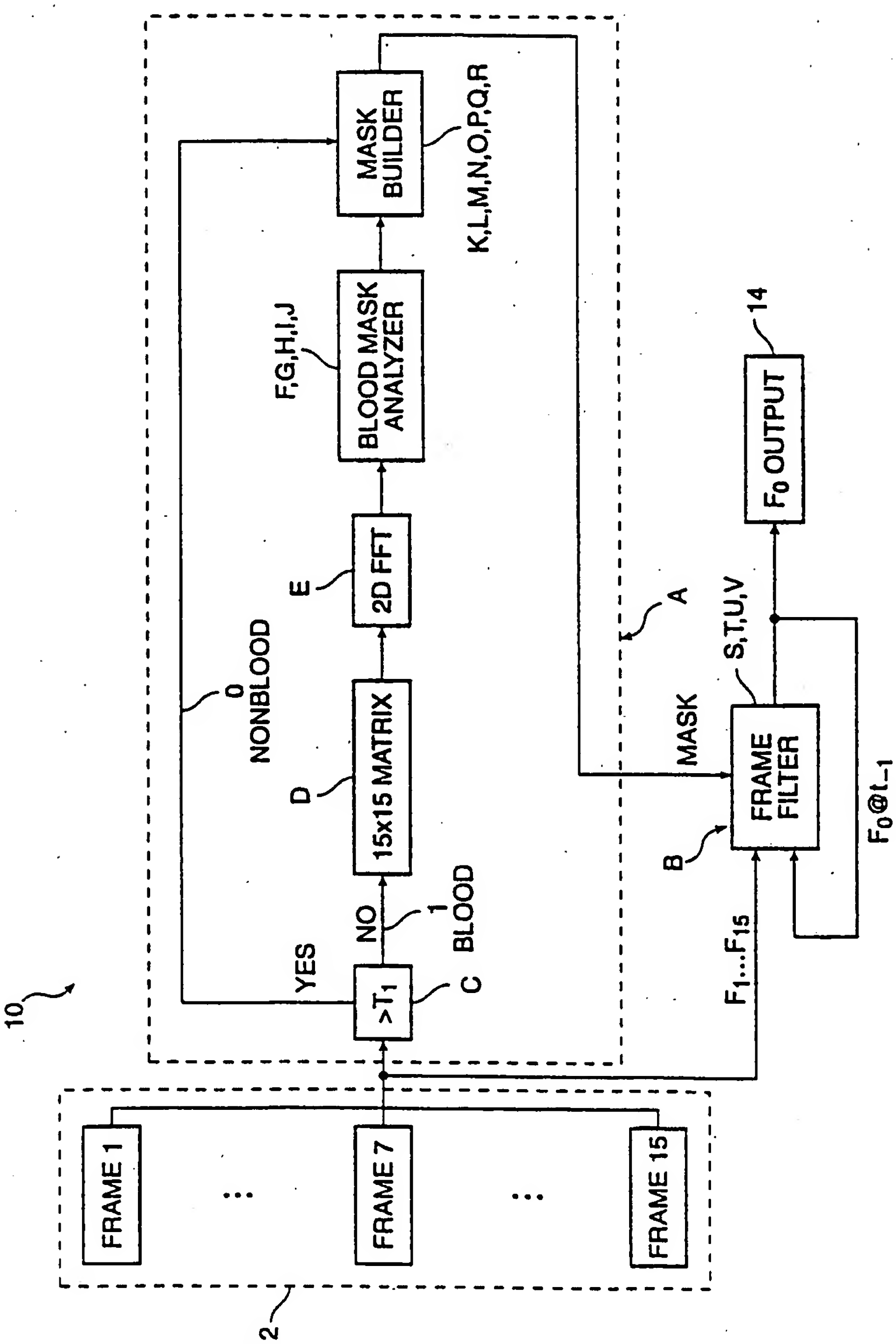
for the center frame and adjacent frames in sequence, and processed frame data for a prior output frame, in order to obtain a center output frame identifying blood regions and non-blood regions;

said binary mask generator comprising:

a signal transformer for converting a block of time domain components and spatial components into the frequency domain in order to permit analysis of temporal and spatial characteristics of a center frame;

means for computing a ratio of higher frequency components to lower frequency components; and

comparator means for comparing said ratio to a threshold ratio in order to distinguish between blood regions and non-blood regions on a spectral basis in the frequency domain.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FRAME 7
FRAME 15
12
10
>T1
C
YES
NO
1
BLOOD
0
NONBLOOD
15x15 MATRIX
D
2D FFT
E
BLOOD MASK ANALYZER
F,G,H,I,J
MASK BUILDER
K,L,M,N,O,P,Q,R
A
MASK
FRAME FILTER
B
S,T,U,V
F0 OUTPUT
14
F1...F15
F0@t-1

FIG. 1

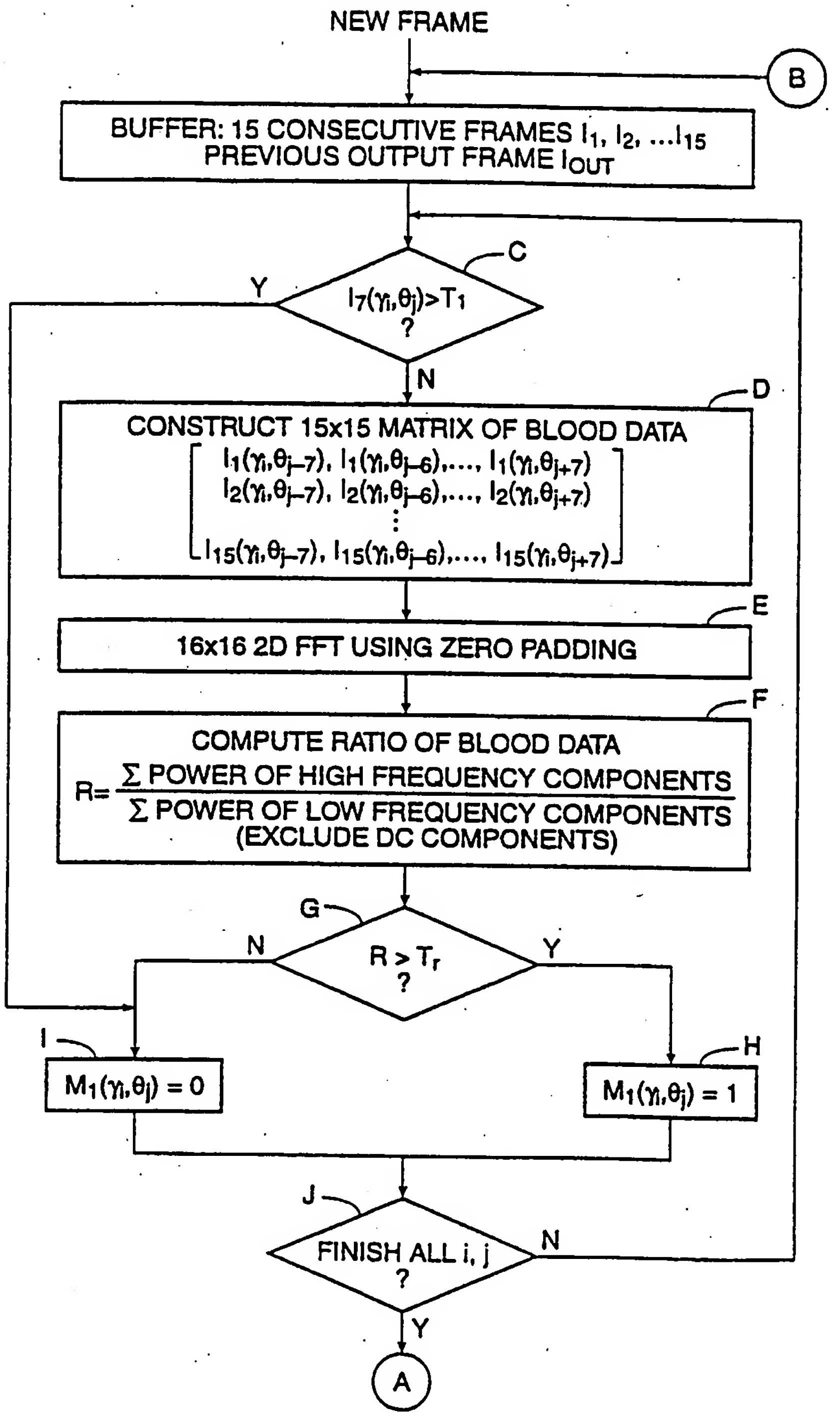
NEW FRAME
B
BUFFER: 15 CONSECUTIVE FRAMES I1, I2, ...I15
PREVIOUS OUTPUT FRAME IOUT
C
I7(γi,θj)>T1
?
Y
N
D
CONSTRUCT 15x15 MATRIX OF BLOOD DATA
I1(γi,θj−7), I1(γi,θj−6),...., I1(γi,θj+7)
I2(γi,θj−7), I2(γi,θj−6),...., I2(γi,θj+7)
I15(γi,θj−7), I15(γi,θj−6),...., I15(γi,θj+7)
E
16x16 2D FFT USING ZERO PADDING
F
COMPUTE RATIO OF BLOOD DATA
R= Σ POWER OF HIGH FREQUENCY COMPONENTS / Σ POWER OF LOW FREQUENCY COMPONENTS
(EXCLUDE DC COMPONENTS)
G
R > Tr
?
N
Y
I
M1(γi,θj) = 0
H
M1(γi,θj) = 1
J
FINISH ALL i, j
?
N
Y
A

FIG. 2A

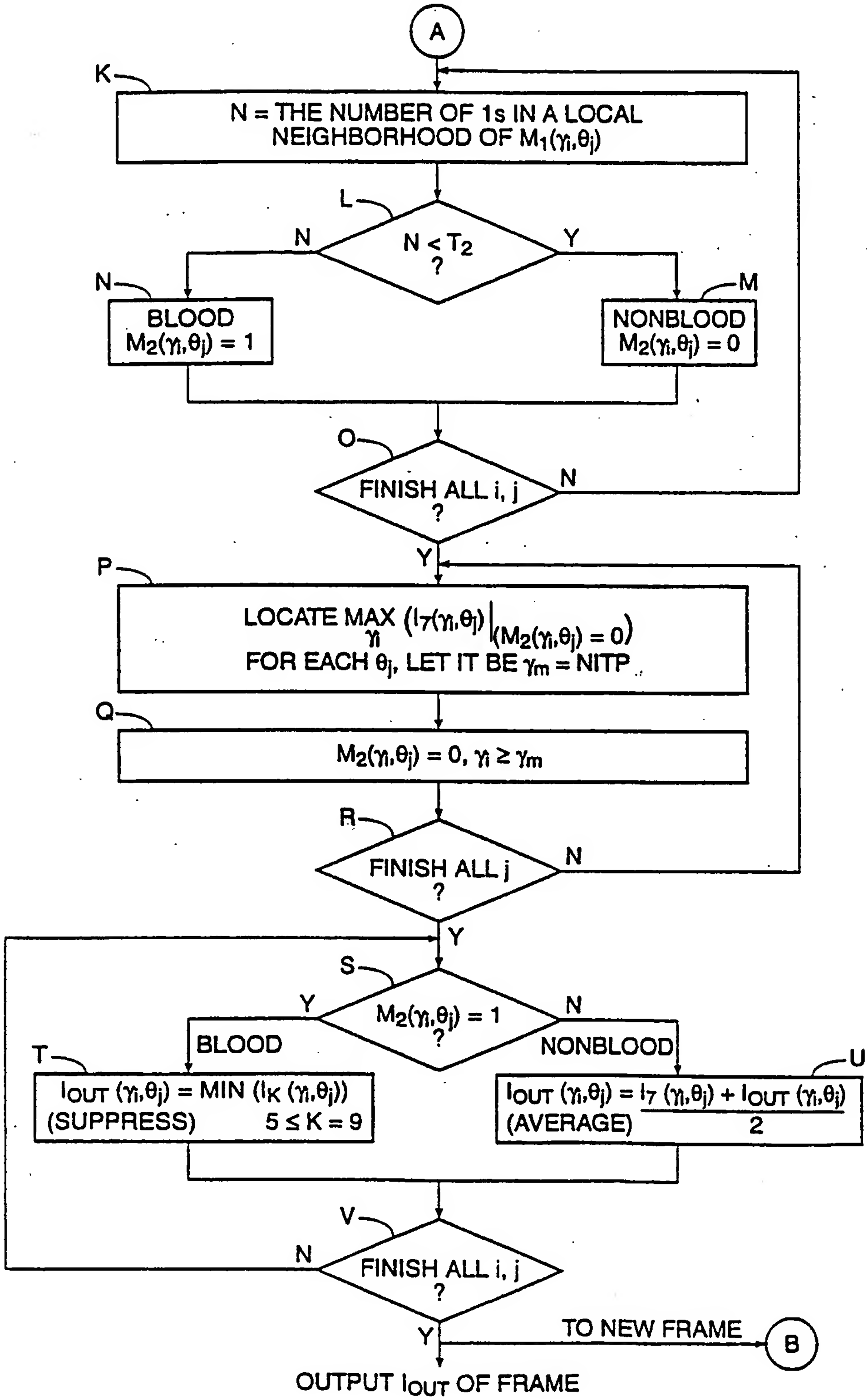
A
K
N = THE NUMBER OF 1s IN A LOCAL NEIGHBORHOOD OF M1(γi,θj)
L
N < T2 ?
N
Y
N
BLOOD M2(γi,θj) = 1
M
NONBLOOD M2(γi,θj) = 0
O
FINISH ALL i, j ?
N
Y
P
LOCATE MAX (I7(γi,θj)|(M2(γi,θj) = 0)
FOR EACH θj, LET IT BE γm = NITP
Q
M2(γi,θj) = 0, γi ≥ γm
R
FINISH ALL j ?
N
Y
S
M2(γi,θj) = 1 ?
Y
N
BLOOD
NONBLOOD
T
IOUT (γi,θj) = MIN (IK (γi,θj))
(SUPPRESS) 5 ≤ K = 9
U
IOUT (γi,θj) = I7 (γi,θj) + IOUT (γi,θj) / 2
(AVERAGE)
V
FINISH ALL i, j ?
N
Y
TO NEW FRAME
B
OUTPUT IOUT OF FRAME

FIG. 2B

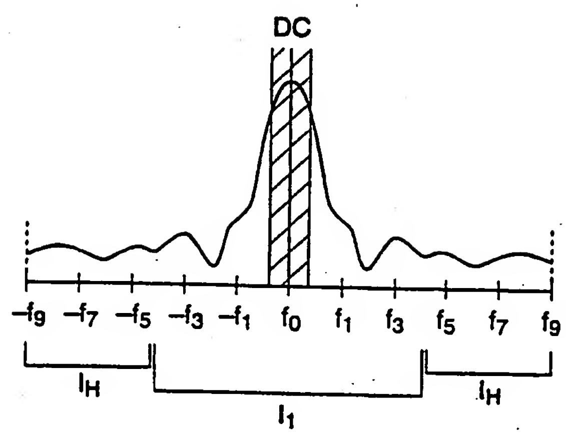

FIG. 3

INTERNATIONAL SEARCH REPORT

Interr ·ional Application No
PC1/IB 99/01346

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S7/52 G01S15/89

According to International Patent Classification (IPC) or to both national classification and IPC

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 571 084 A (HEWLETT PACKARD CO) 24 November 1993 (1993-11-24) column 2, line 2 - line 32 column 3, line 37 -column 4, line 57	1-13
A	US 5 417 215 A (EVANS STEVEN J ET AL) 23 May 1995 (1995-05-23) figure 3	1-13
A	US 5 476 096 A (BAKKE TORBJORN ET AL) 19 December 1995 (1995-12-19) cited in the application abstract	1-13

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☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IB 99/01346

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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